Circularly Polarized Patch Array Antenna with Enhanced Isolation Characteristic

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Abstract

The design of an integrated rectangular microstrip patch array antenna with enhanced isolation characteristic between transmitter and receiver is presented to produce a full-duplex transceiver with transmit and receive operation at the same frequency and with the same polarization. This integrated circulator-like antenna has potential uses in both short-range communication systems and radar.

Keywords : Isolation, Circularly polarized patch array antenna.

1. Introduction

The increasing demand for communication systems has called for the design of low-cost and small-size radio frequency and microwave transceivers. Integrated antennas are attractive solutions for compact antenna-circuit modules in the present scenario of increase in demand by the system designers for the implementation of more complex functions in reduced space. A circulator is in general a three-port device in which signals pass from one port to another in one direction only. It is used to separate transmit and receive paths in communication systems or radars. In practical applications, the isolation of circulator is critically affected by the antenna impedance variation. Due to the limited isolation or reflection, a significant amount of Tx carrier might leak into the receiver and cause several practical difficulties; the receiver must be designed for a very high dynamic range and result in requiring increased area and power consumption. In order to mitigate these strong requirements, various circulators [1-5] have been of interest for many years.

In this paper, we proposed an integrated rectangular microstrip patch array antenna with enhanced Tx/Rx isolation characteristic which is partially-circulator-like function. It is presented to produce a full-duplex transceiver with transmit and receive operation at the same frequency and with the same circular polarization.

2. Antenna Design

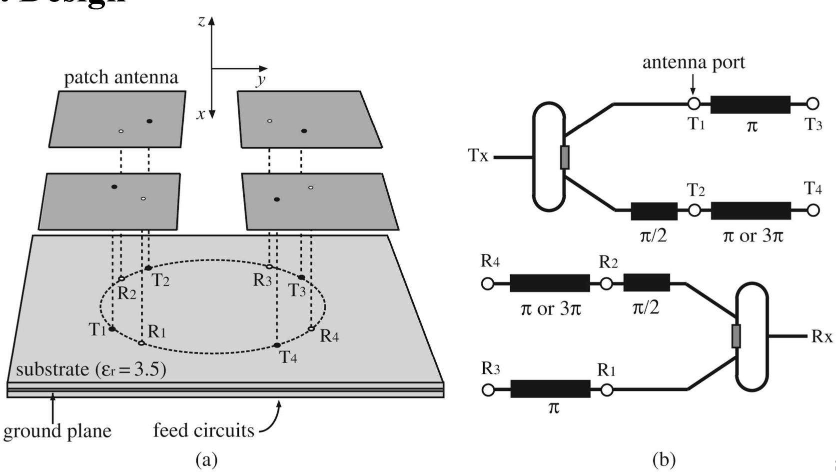

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Fig. 1. (a) geometry of the proposed structure with enhanced Tx/Rx isolation, (b) Tx and Rx feed circuits.

Fig. 1 illustrates the structure of the circularly polarized microstrip patch array antenna which consists of 4 microstrip patch antennas and each antenna is connected to feed circuits through the Tx/Rx antenna port. Fig. 1(b) shows the feed circulator circuit for Tx/Rx. Tx/Rx input signals are connected to the 4 antenna ports through the power divider and the delay line. Each antenna is fed by equal amplitudes but with relative quadrature phase differences. This type of phase distribution is obtained by using a microstrip feed network consisting of Wilkinson power divider, 90 delay line and two 180 delay lines. The magnitude of the signal passed from Tx/Rx input to antenna port is represented as follows.

$$A_{\mathrm{OUT}} = \frac{1}{4} e^{-j\theta} (1 - |\Gamma|^2) A_{Tx} \ , \tag{1}$$

where θ denotes the phase delay between input and antenna port, and Γ indicates reflection coefficient of the antenna. From the equation (1), feed circuits connect the input to the antenna without attenuation when the antenna is well-matched (Γ=0) (‘through’).

Tx/Rx antenna ports are equidistantly placed on the same circumference. Tx input signal is radiated by Tx microstrip patch antenna through Tx feed circuit while some of the Tx input signal are coupled to Rx antenna port. The signals of Rx antenna port are combined at the Rx port through Rx feed circuit. By this process, the signal from the Rx port presents Tx/Rx isolation characteristic. Consider the equivalent circuit model of the proposed antenna array with circulator in Fig. 2. The Tx leakage signal amplitude is represented as follows [5]:

$$b = \sum_{n=1}^{4} \sum_{m=1}^{4} M_{R_n T_m} e^{\frac{-j(n+m-2)\pi}{2}} a$$
$$[M] = \begin{bmatrix} M_{R_1T_1} & M_{R_1T_2} & M_{R_1T_3} & M_{R_1T_4} \\ M_{R_2T_1} & M_{R_2T_2} & M_{R_2T_3} & M_{R_2T_4} \\ M_{R_3T_1} & M_{R_3T_2} & M_{R_3T_3} & M_{R_3T_4} \\ M_{R_4T_1} & M_{R_4T_2} & M_{R_4T_3} & M_{R_4T_4} \end{bmatrix} \tag{2}$$

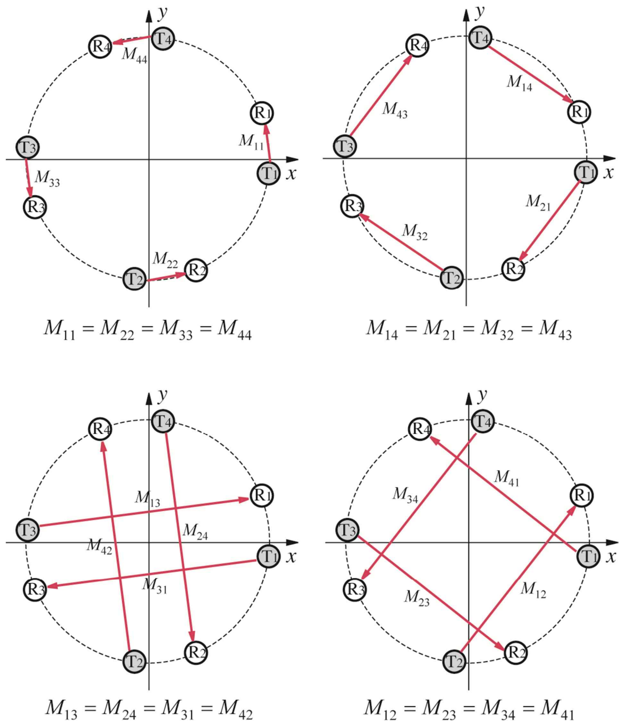
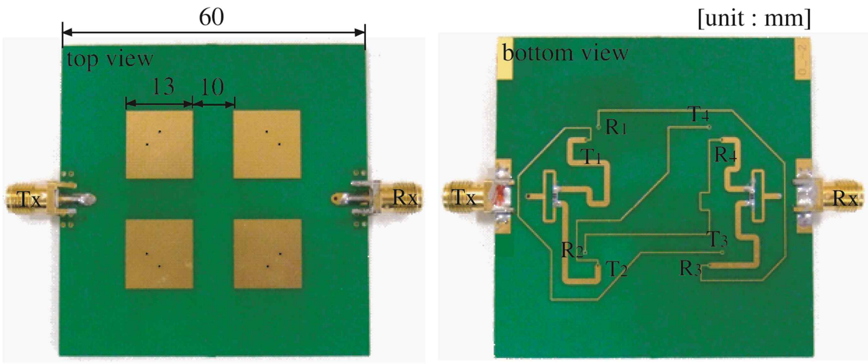


Fig. 2. Equivalent mutual coupling relation between Tx and Rx antenna .



(a) (b)

Fig. 3. Photograph of the antenna array and the feed network: (a) top view, (b) bottom view.

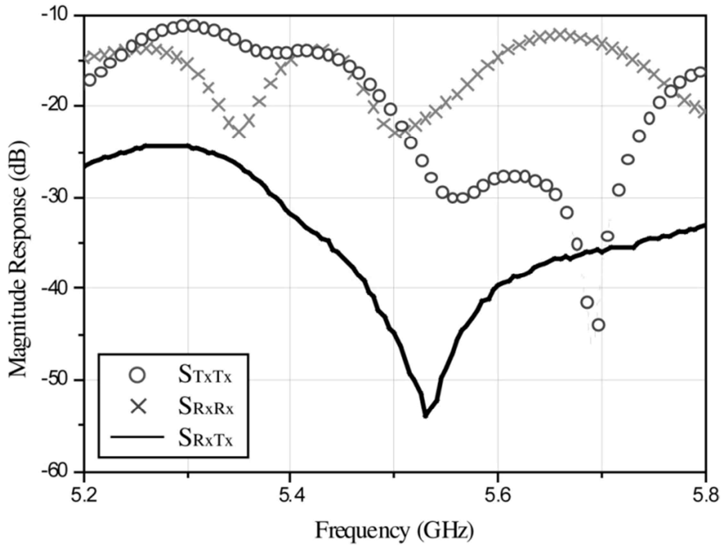


Fig. 4. Measured isolation between transmit and receive ports.

where T_m and R_n indicate the antenna ports of the Tx and the Rx, respectively. The matrix M_{RnTm} means the mutual coupling between m-port Tx and n-port Rx. *b* and *a* are the signal strengths of the Tx leakage and Tx input. If the Tx and Rx ports are placed on the same circumference and the angle of Tx and Rx ports are all right angles as shown in Fig. 1a, the mutual coupling matrix can be rewritten as follows :

$$[M]=\begin{bmatrix} M_{R_1T_1} & M_{R_1T_2} & M_{R_1T_3} & M_{R_1T_4} \\ M_{R_1T_4} & M_{R_1T_1} & M_{R_1T_2} & M_{R_1T_3} \\ M_{R_1T_3} & M_{R_1T_4} & M_{R_1T_1} & M_{R_1T_2} \\ M_{R_1T_2} & M_{R_1T_3} & M_{R_1T_4} & M_{R_1T_1} \end{bmatrix} \tag{3}$$

In this case, substituting (3) into (2) makes b is zero and Tx and Rx are perfectly isolated. The prototype antenna-circulator is fabricated on 3-layer printed circuit board (Taconic's RF-35 substrate with dielectric constant of 3.5 and thickness of 0.76mm (Fig. 3)). The 2x2 rectangular patch array and the feed network for circular polarization are implemented on the top layer and the bottom layer, respectively. The middle layer is used as a ground plane. Fig. 4 shows the measured isolation between transmit and receive ports. The isolation of about 54 dB is obtained at 5.53 GHz which means that the isolation is enhanced compared to the normal circulator. Fig. 5 shows the measured radiation pattern of transmit and receive array antenna at 5.5GHz. The gain of the array antenna is about 6 dBic and the axial ratio is less than 2 dB.

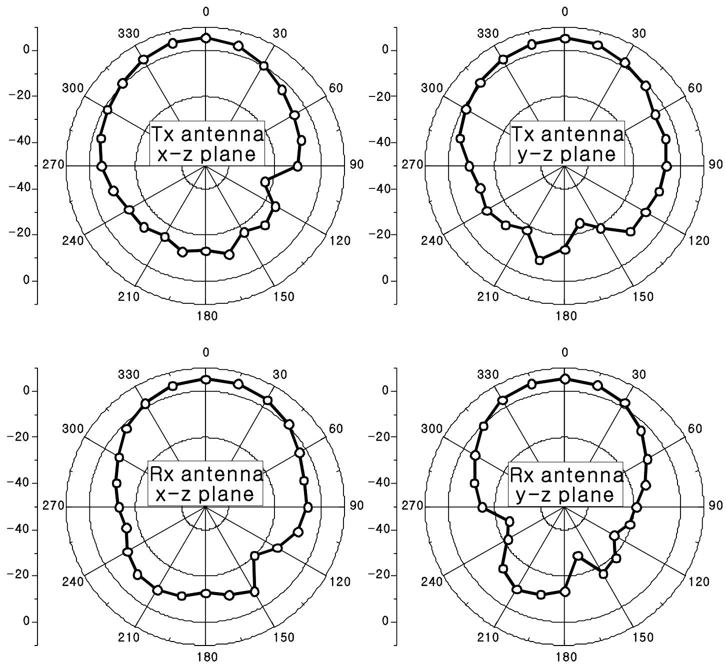


Fig. 5. Measured radiation 2D pattern for the Tx and Rx antennas.

3. Conclusion

The design of the integrated microstrip patch array antenna with enhanced isolation has been presented and measured. The isolation of about 54 dB is obtained at 5.53 GHz and the gain of the array antenna is about 6 dBic and the axial ratio is less than 2 dB. The proposed structure can produce a full-duplex transceiver with transmit and receive operation at the same frequency and with the same polarization. It also shows the possibility of using larger arrays of this type in millimetre wave bands for short-range communications or radar systems.

References

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Acknowledgments

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